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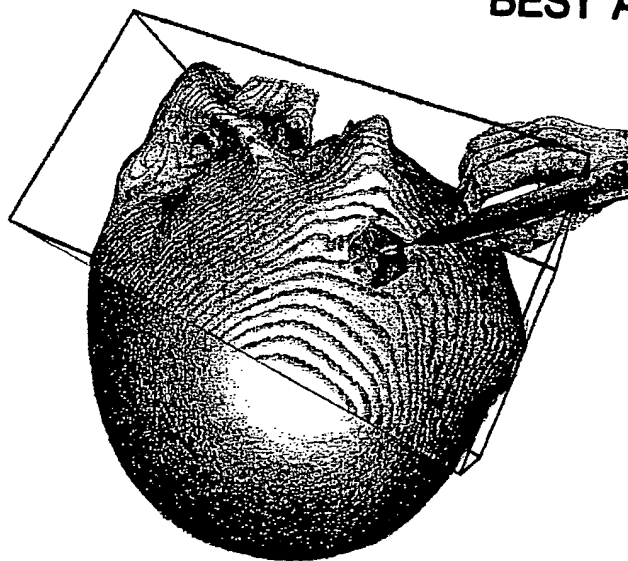
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- (71) Applicant (*for all designated States except US*): **VOLUME INTERACTIONS PTE LTD** [SG/SG]; 5 Shenton Way, #37-04 UIC Building, Singapore 068808 (SG).
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- (72) Inventor; and
- (75) Inventor/Applicant (*for US only*): **KOCKRO, Ralf, Alfons** [DE/SG]; 530 East Coast Road, #19-04 Ocean Park, Eucalia Block, Singapore 458970 (SG).
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- (74) Agent: **GREENE-KELLY, James, Patrick**; Lloyd Wise, Tanjong Pagar, P.O. Box 636, Singapore 910816 (SG).
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(54) Title: A GUIDE SYSTEM AND A PROBE THEREFOR

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Virtual and real images overlaid together

(57) Abstract: A probe to be held by a surgeon who performs an operation within a defined region is proposed. The surgeon employs an image-based guide system having a head-mounted semi-transparent display for displaying computer-generated images of the patient overlying real images of the patient. The position of the probe is tracked by the system and is visible to the surgeon. The computer-generated image includes a line extending from the probe along its longitudinal axis. The surgeon can control the extension of the line, to signal to the system a distance into the patient. The images seen by the user are modified accordingly, to facilitate navigation or simulate an operation.

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A guide system and a probe therefor.

Field of the invention

The present invention relates to a guide system, more particularly but not exclusively to a surgical navigation system for aiding a surgeon in performing an operation. The
5 invention further relates to a method and device for controlling such a system.

Background of the invention

Image guidance systems have been widely adopted in neurosurgery and have been proven to increase the accuracy and reduce the invasiveness of a wide range of
10 surgical procedures. Currently, image guided surgical systems ("Navigation Systems") are based on a series of images constructed from data gathered before the operation (for example by MRI or CT) which are registered in relation to the patient in the physical world by means of an optical tracking system. To do this, detecting markers are placed on the skin of the patient and they are correlated with
15 their counterparts visible on the imaging data. During the surgical operation the images are displayed on a screen in 3 orthogonal planes through the image volume, while the surgeon holds a probe that is tracked by the tracking system. When the probe is introduced into the surgical field, the position of the probe tip is represented as an icon drawn on the images. By linking the preoperative imaging data with the
20 actual surgical space, navigation systems provide the surgeon with valuable information about the exact localisation of a tool in relation to the surrounding structures and help to relate the intra-operative status to the pre-operative planning.

Despite these strengths, the current navigation systems suffer from various shortcomings.

25 Firstly, the surgeon needs to look at the computer monitor and away from the surgical scene during the navigation procedure. This tends to interrupt the surgical workflow and in practice often results in the operation being a two-people job, with the surgeon looking at the surgical scene through the microscope and his assistant looking at the monitor and prompting him.

Secondly, the interaction with the images during the surgery (e.g. switching between CT and MRI, changing the screen windows, activating markers or segmented structures from the planning phase, colour and contrast adjustments) requires the operation of a keyboard, a mouse or a touch screen, which is distracting for the surgeon and troublesome since the equipment needs to be packed with sterile drape. Although probe-type control devices have been proposed (see Hinckley K, Pausch R, Goble C J, Kassel N,F: A Survey of Design Issues in Spatial Input, Proceedings of ACM UIST'94 Symposium on User Interface Software & Technology, pp. 213-222; and Mackinlay J, Card S, Robertson G: Rapid Controlled Movement Through a Virtual 3D Workspace, Comp. Grap., 24 (4), 1990, 171-176), all have shortcomings in use.

Thirdly, a common problem to all current navigation systems which present imaging data as 2D orthogonal slices is the fact that the surgeon has to relate the spatial orientation of the image series including their mentally reconstructed 3D information to the orientation of the patient's head, which is covered during the operation.

A system that uses see-through augmentation by combining the naked eye view of the patient with the computer-generated images is currently under investigation (see Blackwell M, O'Toole RV, Morgan F, Gregor L: Performance and Accuracy experiments with 3D and 2D Image overlay systems. Proceedings of MRCAS 95, Baltimore, USA, 1995, pp 312-317; and DiGioia, Anthony M., Branislav Jaramaz, Robert V. O'Toole, David A. Simon, and Takeo Kanade. Medical Robotics And Computer Assisted Surgery In Orthopaedics. In Interactive Technology and the New Paradigm for Healthcare, ed. K. Morgan, R.M. Satava, H.B. Sieberg, R. Mattheus, and J.P. Christensen. 88-90. IOS Press, 1995). In this system, an inverted image on an upside-down monitor is overlaid over the surgical scene with a half-silvered mirror to combine the images. The user wears a head tracking system while looking onto the mirror and the patient beneath. However, the authors report significant inaccuracies between the virtual and the real object.

Other systems currently under research or development combine computer-generated images with the video of the surgical scene obtained through cameras placed at fixed positions in the operation theatre or a head mounted display of the

- user. The combined signal is then channelled into the HMD ("Head Mounted Display") of a user. The three examples of such projects are disclosed at in Fuchs H, Mark A, Livingston, Ramesh Raskar, D'nardo Colucci, Kurtis Keller, Andrei State, Jessica R. Crawford, Paul Rademacher, Samuel H. Drake, and Anthony A. Meyer, MD. Augmented Reality Visualization for Laparoscopic Surgery. Proceedings of First International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI '98), 11-13 October 1998, Massachusetts Institute of Technology, Cambridge, MA, USA; Fuchs H, State A, Pisano ED, Garrett WF, Gentaro Hirota, Mark A. Livingston, Mary C. Whitton, Pizer SM. (Towards) Performing Ultrasound-Guided Needle Biopsies from within a Head-Mounted Display. Proceedings of Visualization in Biomedical Computing 1996, (Hamburg, Germany, September 22-25, 1996), pgs. 591-600; and State, Andrei, Mark A. Livingston, Gentaro Hirota, William F. Garrett, Mary C. Whitton, Henry Fuchs, and Etta D. Pisano (MD). Technologies for Augmented-Reality Systems: realizing Ultrasound-Guided Needle Biopsies. Proceedings of SIGGRAPH 96 (New Orleans, LA, August 4-9, 1996), in Computer Graphics Proceedings, Annual Conference Series 1996, ACM SIGGRAPH, pgs. 439-446.

Another technique (disclosed in Edwards PJ, Hawkes DJ, Hill DLG, Jewell D, Spink R, Strong A, Gleeson M: Augmented reality in the stereo microscope for Otolaryngology and neurosurgical Guidance. Proceedings of MRCAS 95, Baltimore, USA, 1995, pp 8-15) uses an operating microscope as a device for overlaid display of 3D graphics. By "image injection" of stereoscopic structures into the optical channels of the microscope the surgeon sees the superimposed image over the surgical scene. This technique overlays simple meshes with a relatively low resolution onto the surgical scene, without providing any interactive capabilities. The authors report difficulties regarding the stereoscopic perception of the overlaid data in relation to the real view.

Although meant for guidance of the user, these techniques are all limited in application and usability.

Summary of the invention

The present invention aims to address at least one of the above problems, and to propose new and useful navigation systems and methods and devices for controlling them.

- 5 The present invention is particularly concerned with a system which can be used during a surgical operation. However, the applicability of the invention is not limited to surgical operations, and the systems and methods discussed below may find a use in the context of any delicate operation, and indeed during a planning stage as well as an intra-operative stage.
- 10 The present invention is motivated by noting that during the navigation procedure in a surgical operating room it is critical to be able easily and quickly to interact with a surgical navigation system, for example to alter the format of the computer-generated images. In addition, it would be advantageous to be able to simulate certain surgical procedures directly at the surgical site by using the computer-generated images.
- 15 In general terms, the present invention proposes a probe to be held by a user who performs an operation (e.g. a surgical operation) within a defined region while employing an image-based guide system having a display for displaying computer-generated images (3D and/or 2D slices) of the subject of the operation. The probe has a position which is tracked by the system and which is visible to the user (for
20 example, because the system allows the user to see the probe directly, or alternatively because the computer-generated images include an icon representing its position). By moving the probe, the user is able to enter information into the system to control it, such as to cause changes in the physical shape of the subject in the image presented by the computer.
- 25 According to a first aspect, the invention provides a guide system for use by a user who performs an operation in a defined region, the system including a data processing apparatus for generating an image of the subject of the operation, a display for displaying the image to the user in co-registration with the subject, a probe having a longitudinal axis and having a position which is visible to the user, and a

tracking unit for tracking the location of the probe by the system and transmitting that location to the data processing apparatus,

the data processing apparatus being arranged to generate the image according to a line extending parallel to the longitudinal axis of the probe, the line
5 having an extension which is controlled according to the output of an extension control device controlled by the user, and

and the data processing apparatus further being controlled to modify the image of the subject of the operation according to the controlled extension of the line.

For example, if the computer-generated display displays an image of a patient which
10 is a section through the patient in at least one selected plane, this length of the line may be chosen to determine the plane(s), e.g. to be that plane which is orthogonal to the probe's length direction and at the distance from the tip of the probe corresponding to the length of the line.

Alternatively or additionally, the user may be able to use the variable extension to
15 control a virtual surgical operation on a virtual subject represented to the user by the computer-generated images. One such suitable virtual surgical operation is removal of portions of the computer-generated image to a depth within the patient indicated by the extension of the probe, to simulate a removal of corresponding real tissue by the surgeon. Preferably, such virtual operations may be reversed. The usage of the
20 probe to cause this operation is preferably selected to resemble as closely as possible the usage of a real tool which the surgeon would use to perform the corresponding real operation. In this way, a surgeon may be permitted to perform the operation virtually, once, more than once, or even many times, before having to perform it in reality.

25 In a second aspect, the invention proposes a guide system for use by a user who performs an operation in a defined three-dimensional region, the system including:

a data processing apparatus for generating an image of the subject of the operation in co-registration with the subject,

a display for displaying the image to the user, a probe having a position which is visible to the user, and

a tracking unit for tracking the location of the probe by the system and transmitting that location to the data processing apparatus,

- 5 the data processing apparatus being arranged to modify the image to represent a change in the physical shape of the subject of the operation, the modification depending upon the tracked location of the probe.

- Most preferably, in both aspects of the invention, the computer-generated images are overlaid on the real image of the subject. The computer-generated images are
10 preferably displayed in a semitransparent head-mounted stereo display (HMD), to be worn by a surgeon, so that he or she sees the computer-generated images overlying the real view of the subject of the operation obtained through the semi-transparent display (e.g. semi-transparent eye-pieces). The HDM is tracked, and the computer generates images based on this tracking, so that as the surgeon moves, the real and
15 computer-generated images remain in register.

- The system can be used in two modes. Firstly, during macroscopic surgery the user looks through the display in semi-transparent mode and sees stereoscopic computer graphics overlaid over the surgical field. This will enable the surgeon see "beyond the normal line of sight" before an incision is made, e.g. visualising the position of a
20 tumour, the skull base or other target structures.

- Secondly, for microscopic surgery the same stereo display can be attached to (e.g. on top of the binocular of) a stereoscopic microscope, the position of which is tracked (as an alternative to tracking movements of the user). The computer graphics in the display may be linked to the magnification and focus parameters of the tracked
25 microscope and therefore reflect a "virtual" view into the surgical field

The 3D data presented in the display may be computer-generated by a computational neurosurgical planning package called VizDexter, which was previously published under the name VIVIAN and was developed by Volume Interactions of Singapore. VizDexter allows the employment of multimodal (CT and

MRI fused) images in the Virtual Reality environment of the "Dextroscope" (for example, as disclosed in Kockro RA, Serra L, Yeo TT, Chumpon C, Sitoh YY, Chua GG, Ng Hern, Lee E, Lee YH, Nowinski WL: Planning Simulation of Neurosurgery in a Virtual Reality Environment. Neurosurgery Journal 46[1], 118-137. 2000.9, and in

5 Serra L, Kockro RA, Chua GG, Ng H, Lee E, Lee YH, Chan C, Nowinski W: Multimodal Volume-based Tumor Neurosurgery Planning in the Virtual Workbench, Proceedings of the First International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI), Massachusetts, Institute of Technology, Cambridge MA, USA, October 11-13, 1998, pp.1007-1016. The disclosure of these

10 publications is incorporated herein in its entirety by reference).

Using the invention, it is possible to simulate a surgical operation directly at the surgical site by using the real images of the patient in combination with the precisely co-registered, and optionally overlaid, 3D data.

Although the invention has been expressed above in terms of a system, it may

15 alternatively be expressed as a method carried out by the user of the system.

Brief description of the figures

A non-limiting embodiment of the invention will now be described for the sake of example only with reference to the following figures, in which:

20 Fig. 1 shows a system which is an embodiment of the present invention in use during a surgical operation;

Fig. 2 shows the virtual bounding box and its relationship in the embodiment to the probe and the virtual control panel;

Fig. 3 shows the control panel as generated by the embodiment;

25 Fig. 4 illustrates a concept of small wrist movements controlling buttons on a distant panel in the embodiment;

Fig. 5 shows use of the virtual extendible probe as a navigation tool in the embodiment; and

Figs. 6a - c show use of the virtual extendible drill in a virtual operation using the embodiment.

5 Detailed Description of the embodiment

Prior to performance of a surgical operation using the embodiment of the invention, the patient is scanned, such as by standard CT and/or MRI scanners. The image series thus generated is transferred to the VR environment of the Dextroscope and the data is co-registered and displayed as a multimodal stereoscopic object, in the
10 manner disclosed in the publications describing the Dextroscope referred to above. During the planning session in the Dextroscope, the user identifies relevant surgical structures and displays them as 3D objects (a process called segmentation). Additionally, landmarks and surgical paths can be marked. Before the actual operation the 3D data is transferred to the navigation system in the OR ("operating
15 room", also known as "operating theatre").

The system which is an embodiment of the present invention is shown schematically in Fig. 1, in which the various elements are not shown to scale. The system includes a stereo LCD head mounted display (HMD) 1 (we presently use a SONY LDI 100). The display may be worn by a user, or alternatively it may be mounted on and
20 connected to an operating microscope 3 supported on a structure 5. The system further includes an optical tracking unit 7 which tracks the position of a probe 9, as well as the positions of the HMD 1 and the microscope 3. Such a tracking unit 7 is available commercially (Northern Digital, Polaris). The system further includes a computer 11 which is capable of real time stereoscopic graphics rendering, and
25 transmitting the computer-generated images to the HDM 1 via cable 13. The system further includes a footswitch 15, which transmits signals to the computer 11 via cable 17. Furthermore, the settings of the microscope 3 are transmitted (as discussed below) to the computer 11 via cable 19. The subject of the operation is shown as 21.

We use a passive tracking unit 7, which operates by detecting three reflective
30 spherical markers attached to an object. By knowing and calibrating the shape of an

object carrying the markers (such as pen shaped probe 9), its exact position can be determined in the 3D space covered by the two cameras of the tracking system. In order to track the LCD display 1, three markers were attached along its upper frontal edge (close to the forehead of the person wearing the display). The microscope 3 is tracked by reflective makers, which are mounted to a custom-made support structure attached to the microscope 3 in such a way that a free line of sight to the cameras of the Navigation system is provided during most of the microscope movements. On top of the binocular, a second support structure allows the LCD display 1 to be mounted during microscopic surgery. The Polaris tracking unit 7 and the microscope 3 communicate with the computer 11 via its serial port. Connected to the another computer port is the footswitch 15 for interaction with the virtual interface during the surgical procedure.

The head of the patient 21 is registered to the volumetric preoperative data with the aid of skin markers (fiducials) which are glued to the skin before the imaging procedure and which remain on the skin until the surgery starts (normally a minimum of six fiducials are required). During the pre-operative planning procedure in the Dextroscope, the markers are identified and marked. In the operating theatre, a probe tracked by the tracking system is used to point to the fiducials in the real world (on the skin) that correspond to those marked on the images. The 3D data is then registered to the patient using a simple semi-automated registration procedure. The registration procedure yields a transformation matrix which transforms the virtual world to correspond to the real world. This registration procedure is standard in most modern neurosurgical navigation systems.

After completing the image to patient registration procedure, the surgeon wears the HMD 1 and looks at the patient 21 through the semi-transparent screen of the display 1 where the stereoscopic reconstruction of the segmented imaging data is displayed. The surgeon perceives the 3D data to be overlaid directly on the actual patient and, almost comparable to the ability of X - ray vision, the 3D structures appearing "inside" the head can be viewed from different angles while the viewer is changing position.

Firstly, we will explain the use of the system without the microscope 3. We refer to this as "STAR" (See Through Augmented Reality). We display the right and the left

eye projection of the stereo image generated in the computer 11 on the right and the left LCD of the HMD 1 respectively. After calibrating the size of the patient's head and its distance to the HMD 1, the computer 11 generates an image that corresponds exactly to the surgeon's view of the real patient 21, which allows the surgeon to

5 comprehend the exact correspondence between his surgical concepts developed during the planning and the actual patient 21. Having the virtual target structure in view, the surgeon is able to choose the ideal skin incision, craniotomy and path towards a lesion without ever having to look away from the surgery scene. The applications of STAR extend beyond neurosurgery, for example into the fields of

10 cranio-facial or orthopaedic surgery, where the reconstructive bone work can be carried out more precisely under the virtual guidance of augmented 3D data generated during the planning session.

The user also sees a virtual probe which corresponds to the actual pen-shaped and tracked probe 9 in the surgeon's hand. With this probe the user activates and

15 controls a virtual 3D interface, which allows interaction with the 3D data. The probe itself can also be turned into a unique simulation and navigation tool, as described below.

We now turn to navigation using the microscope 3, a phase referred to here as MAAR (Microscope assisted augmented reality). In this phase of the usage of the

20 system of Fig. 1, the HMD 1 is attached to the support structure 5 above the microscope's binocular and the see-through mode of the HMD 1 is switched off, to just leave images supplied by the computer 11. These images are a combination of the stereoscopic video output of the microscope 3 (both right and left channel, transmitted to the computer 11 via cable 19) as well as the stereoscopic, segmented

25 3D imaging data generated by the computer 11 itself. The images are displayed in the HMD 1, and their respective signal intensity is adjustable by a video mixer. In order to navigate by means of the 3D data in the display the data needs to be exactly matched with the actual view through the microscope (or its video signal respectively). To do this, the computer 11 employs a knowledge of the settings of

30 the optics of the microscope 3 to help generate the 3D graphics. The microscope's motor values for the zoom and focus are read from the microscope via the serial port (RS232 interface) and transmitted to the computer 11. Then the actual magnification

and the plane of focus are calculated using predefined formulae. The position and the orientation (pose) of the microscope are obtained from the optical tracking system. The computer 11 then generates a computer-generated image which matches the microscope magnification, plane of focus, and the viewpoint as a
5 stereoscopic image of the 3D imaging data. This image is displayed in the HMD 1. Since the exact image is generated online, using the workings of the microscope optics, the surgeon can conveniently vary the zoom and focus values intra-operatively without the camera calibration or the system performance being affected. Since the microscope 3 is tracked in real time, the surgeon can freely move the
10 microscope 3 around to get various viewpoints. By coupling the crop plane to the focus plane of the microscope 3, the user can slice through the virtual 3D imaging data planes by changing the focus values of the microscope.

In both STAR and MAAR, the interaction with the virtual objects is possible in real-time by using the tracked probe 9, which is displayed as a virtual probe within the
15 computer-generated images presented to the user by the HMD 1.

Note that although the invention is explained above in terms of the images being fed into a HMD 1 which is separable from the microscope 3, an alternative within the scope of the invention is to overlaying the 3D computer-generated data directly onto the view through the microscope 3 by using an LCD based image "injection" system
20 into the microscope's optical channels. In this case, there is no need for a separate HMD to perform MAAR

During the navigation procedure, with either MAAR or STAR, the user sees the patient's 3D imaging data augmented over the real surgical scene. Especially since the virtual data usually consists of different imaging studies and their 3D
25 segmentations (such as tumours, blood vessels, parts of the skull base, markers and landmarks) the user needs to be able to interact with the data during the operation in order to adapt it to the navigational needs. Tools are needed for example to hide/show or to control the transparency of 3D data, to adjust cropping planes, to measure distances or to import data. According to the present invention, the surgeon
30 can interact with the computer 11 in this way to modify 3D data displayed in the HMD

1 by using only the passively tracked pen-shaped probe 9 and the footswitch 15, and thus circumventing the use of keyboard and mouse in the OR.

When the surgeon is moving the tracked probe near the patient's head, the probe 9 is within a virtual bounding box, which we have defined around the patient's head.

- 5 This is illustrated in Figure 2(a). The positions of the markers is shown as 25. The bounding box (which is in real space, not virtual space) is shown dashed, surrounding the region of interest in which the surgery occurs. In this situation, the computer-generated images show the user imaging data of the subject. Furthermore, a virtual probe corresponding to probe 9 is displayed in the HMD 1 in a realistically
10 corresponding position to the virtual 3D imaging data.

When the probe is not visible to the tracking system, i.e. its reflective markers are hidden or it is out of the tracking volume, the virtual probe disappears and the surgeon sees only the augmented patient data displayed on the HMD. This is shown in Fig. 2(c).

- 15 When the surgeon moves the probe 9 away from the patient's head and out of the virtual bounding box, but keeps it within the view of the tracking system (as shown in Fig. 2(b)), the visualization system switches the view so that the user only sees a computer-generated image which is a control panel. This panel is shown in Fig. 3. The virtual hand-held probe 27 is then displayed with a ray 29 shooting from its tip
20 which makes it look like as a virtual laser probe in the virtual world. The buttons 31 on the control panel can be selected by pointing the virtual ray at them. Once selected, the buttons can be pressed (switched ON/OFF) using the foot-switch.

- The control panel is placed such that when viewed in stereo it appears to be at a comfortable distance of about 1.5 m from the user. The virtual probe 27 itself reflects
25 the movements of the real probe 9 in the surgeon's hand realistically, which results in the fact that the virtual buttons on the control panel can be pointed at with small wrist movements.

- In the space constraints of the operating room, especially while operating with the operating microscope, the described method of interaction enables the surgeon to
30 comfortably and quickly access a wide range of navigation related tools. Important

are two factors: Firstly, the fact that the virtual space, which activates the floating control panel, is surrounding the patient's head in close distance means that it can be reached by the surgeon with a simple arm movement in any direction away from the patient's head (as long as still being in view of the tracking system). The second
5 important factor is that that once the virtual tool rack is visible, all its tools can be activated by small wrist movements instead of larger movements in the air which could conflict with the surrounding OR equipment. This is important since it allows the surgeon to navigate comfortable, even with his arms rested, while looking at the data in the display without the need to visually control his hand movements and thus
10 without much distraction from the operative workflow. This effect is illustrated in Fig. 4, which shows a ray shooting from the probe's tip.

Within the virtual interface panel the surgeon has access to a suit of functionalities to modify the representation of the data, such as:

- Hide/Show the various imaging modalities and/or 3D objects. Operating in
15 soft tissue for example makes it necessary to switch on some MRI derived segmentations (or the original MRI planes themselves) whereas the CT derives structures need to be switched on during bone work.
- Change the appearance of the data to mono-planar / tri-planar / 3D full volume.
- 20 • Link the imaging data to the probe or the microscope. This means that the online-cropping plane (if the data appears as a 3D volume), the mono plane or the center point of a tri-planar image can be linked either to the focal plane of the microscope or to the virtually extendable probe (described below) which can be brought into the operative field.
- 25 • Activate the virtual probe and its virtual extension and retraction feature to control intra-operative simulation tools like a virtual drill and restorer tool, measurement tools or tools to simulate tissue retraction or clip placement (see 2.6).
- Activate a color and transparency adjustment table.

- Switch between the MAAR and the STAR systems.
- Activate tools to import and register intra-operative imaging data i.e. 3D ultrasound.

5 We have developed a method to turn the virtual probe into a tool, which allows some surgical steps to be navigated and simulated while interacting with the augmented data directly inside the surgical cavity.

Firstly, we will describe the novel navigation function of the embodiment. If volumetric 3D data is linked to the probe (by selecting it in the virtual tool rack, see above), a cropping plane perpendicular to the direction of the tip of the probe is generated.

10 When the surgeon brings the probe to the surgical scene, and presses the foot-switch, the line extending from the probe is virtually elongated and the plane moves away from the tip of the probe (slicing through the patient data) to match the length of the line as long as the footswitch is kept pressed. Once the foot-switch is released the plane stays at the last position. When the foot-switch is pressed the next time, the

15 line shortens and plane moves correspondingly towards the tip of the probe, until the foot-switch is released. This way the cut-plane can be moved in and out by alternately pressing the footswitch and various parts of the data can be examined. At each stage, the computer 11 generates data based on the cut-plane, e.g. as a mono-plane slice of the subject of the operation. The length of the virtual probe extension is

20 displayed on-line to allow the measurement of distances in the depth of the operating cavity. If the data is chosen to appear as a monoplane, this isolated plane is also perpendicular to the probe and it can be moved in and out in the same fashion. If the data appears in tri-planar mode (i.e. as three orthogonal planes meeting at an origin), the triplanar origin is linked to the extendable probe.

25 Alternatively, and optionally, the data generated by the computer 11 can also be linked to the microscope settings and in this case the cutting plane is placed at the plane of focus of the microscope. This plane can then be moved by extending the line from the probe and/or using the focus button on the microscope.

Fig. 5 shows a computer generated image that combines three types of tissue. A

30 bone which is volumetrically reconstructed from Computer Tomography (CT) data is

- shown in white and labelled CT. The Angiography (MRA) data, which shows the blood vessels, is displayed in the image in a second colour such as red (black in the picture). The Magnetic Resonance Imaging data (MRI) shows the soft tissue (in grey), and appears in mono-planar mode in a plane perpendicular to the virtual
- 5 probe. The computer generated image of the MRI is cropped by being linked to the focal plane of the microscope. By extending the probe virtually the MRI plane moves into the depth of the operating field and the user can examine the spatial extent of a lesion (in this case a jugular schwannoma).
- 10 This tool can also be used to provide the surgeon with the online distance to surgically important landmarks placed during the planning stage (typically up to three or four). During navigation, a uniquely colored line is shown from the tip of the probe to each landmark, and the distance from each landmark is displayed next to each line. This display of landmarks can be turned ON/OFF using the floating control
- 15 panel.

- Secondly, we describe novel simulation function which can be performed using the present embodiment. The virtual drill tool consists of a virtual sphere which is attached to the virtual probe and which acts as a drill when introduced into the augmented virtual data by removing voxels (3D pixels) in real time. The spherical drill
- 20 is virtually extendable and retractable by alternately pressing the foot-switch as described above, thereby changing the length of a line drawn extending between the probe and the spherical drill. The surgeon can thus drill at any point by moving the hand-held probe. The combination of real and computer-generated images seen by a user is shown in Fig. 6, in which Fig. 6a shows the virtual image of a skull of a patient together with the virtual tool, Fig. 6b shows the actual skull of the patient with the
- 25 actual pen in the surgeon's hand which would in this case rest with its tip on the real bone or slightly above and Fig. 6c shows the view by the user through the user's head mounted display in which the virtual image of Fig. 6a is overlaid on and in co-registration with the real image of Fig. 6b and in which the visible cavity in the virtual
- 30 bone has been drilled with the extendable voxel-removing sphere.

The system further includes a "restorer tool" which works in a similar fashion to the drill tool, except that it restores the voxels which were removed by the drill tool.

The intra-operative simulation tool provided by this embodiment is especially useful during the minute bone work at the skull base. It enables the surgeon to simulate bone removal along several directions by using the exactly overlaid 3D CT data. The optimal drilling path in relation to the surrounding structures can be explored and rehearsed virtually before the actual bone work is carried out. During the actual drilling, the overlaid virtually drilled data can be exactly followed. Apart from drilling, the described extendable virtual probe can also be used to simulate other surgical operations, such as to retract soft tissue or to place clips or bone screws virtually on the overlaid data before actually doing so during the surgery. It can be generally viewed as a tool, which allows the augmented 3D data to be probed and manipulated right at the surgical site in order to perform the actual subsequent surgical step more accurately and safely.

Although the invention has been explained above with reference to only a single embodiment, various modifications are possible within the scope of the invention as will be clear to a skilled person. For example, it is possible, though not preferable, to omit the representation of the line from the display of Fig. 6, showing only the tool and the probe; the line would still exist conceptually, however, as the controllable distance between the probe and the tool in the longitudinal direction of the tool.

Claims

1. A guide system for use by a user who performs an operation in a defined three-dimensional region, the system including a data processing apparatus for generating an image of the subject of the operation, a display for displaying the image to the user in co-registration with the subject, a probe having a longitudinal axis and having a position which is visible to the user, and a tracking unit for tracking the location of the probe by the system and transmitting that location to the data processing apparatus,
 - 5 the data processing apparatus being arranged to generate the image according to a line extending parallel to the longitudinal axis of the probe, the line having an extension which is controlled according to the output of an extension control device controlled by the user, and
 - 10 and the data processing apparatus further being controlled to modify the image of the subject of the operation according to the controlled extension of the line.
- 15 2. A system according to claim 1 wherein the display is arranged to generate images of the subject of the operation overlaid on the subject.
3. A system according to claim 1 or claim 2 in which the data processing apparatus is arranged to display a section of the subject in a plane within the subject selected by controlling the extension of the line.
- 20 4. A system according to claim 1 or claim 2 in which the data processing apparatus is arranged to modify the computer-generated image to simulate an operation performed on the subject user, the simulated operation being controlled by controlling the extension of the line.
- 25 5. A system according to claim 4 in which the simulated operation includes removal of portions of the computer-generated image to a depth within the patient indicated by the extension of the line.

6. A guide system for use by a user who performs an operation in a defined three-dimensional region, the system including:
- a data processing apparatus for generating an image of the subject of the operation in co-registration with the subject,
- 5 a display for displaying the image to the user, a probe having a position which is visible to the user, and
- a tracking unit for tracking the location of the probe by the system and transmitting that location to the data processing apparatus,
- 10 the data processing apparatus being arranged to modify the image to represent a change in the physical shape of the subject of the operation, the modification depending upon the tracked location of the probe.
7. A system according to claim 6 wherein the data processing apparatus is arranged to generate images of the subject of the operation overlaid on the subject.
8. A system according to claim 6 or claim 7 in which the modification of the image simulates a removal of a part of the subject of the operation, the part being
- 15 determined by the location of the probe.
9. A system according to any preceding claim in which the display is adapted to be mounted on the head of a user, the user being able to view the subject of the operation through the display, so as to see the computer-generated image
- 20 superimposed on a true image of the subject of the image, the tracking unit monitoring the position of the display and transmitting the monitored position of the display to the processing apparatus, which is arranged to modify the computer-generated image according to the position of the display to maintain the computer-generated image and the real image stereoscopically in register.
- 25 10. A system according to any preceding claim in which the display is adapted to be mounted on a microscope, the user being able to view the microscope image through the display, so as to see the computer-generated image superimposed on the microscope image, the tracking unit monitoring the position of the microscope

and transmitting the monitored position of the microscope to the processing apparatus, which is arranged to modify the computer-generated image according to the position of the microscope to maintain the computer-generated image and the real image stereoscopically in register.

- 5 11. A method for use by a user who performs an operation in a defined three-dimensional region with guidance from an image guided system, for modifying the image displayed to the user by the image guided system, the system including a data processing apparatus for generating images of the subject of the operation in co-registration with the subject, a display for displaying the images to the user, a probe
10 having a position which is visible to the user, and a tracking unit for tracking the location of the probe by the system and transmitting that location to the data processing apparatus, the method including:

the user moving the probe to a selection region outside and surrounding the defined region,

- 15 the data processing apparatus registering the position of the probe within the selection region, and thereupon generating within the image one or more virtual buttons, each of the buttons being associated with a corresponding instruction to the system,

- the user selecting one of the buttons, the selection including positioning of the
20 probe in relation to the apparent position of that virtual button, and

the data processing apparatus registering the selection, and modifying the computer-generated image based on the corresponding instruction.

12. A method according to claim 11 wherein the data processing generates images of the subject of the operation overlaid on the subject.

- 25 13. A method according to claim 11 in which, while the data processing apparatus displays the virtual buttons, it further displays a line extending from the probe along a longitudinal axis thereof, the positioning of the probe includes aligning the longitudinal axis of the probe with the button.

14. A method for use by a user who performs an operation in a defined three-dimensional region with guidance from an image guided system, for modifying the image displayed to the user by the image guided system, the system including a data processing apparatus for generating images of the subject of the operation in co-
5 registration with the subject, a display for displaying the images to the user, a probe having a longitudinal axis and a position which is visible to the user, and a tracking unit for tracking the location of the probe by the system and transmitting that location to the data processing apparatus, the method including:
- the data processing apparatus generating the image according to a line
10 extending parallel to the longitudinal axis of the probe,
- the user controlling the extension of the line having an extension using an extension control device, and
- the data processing apparatus modifying the image of the subject of the operation according to the controlled extension of the line.
- 15 15. A method according to claim 14 wherein the data processing generates images of the subject of the operation overlaid on the subject.
16. A method according to claim 14 or claim 15 in which the data processing apparatus modifies the image to display a section of the subject in a plane within the subject selected by controlling the extension of the line.
- 20 17. A method according to claim 16 in which the data processing apparatus is modifies the computer-generated image to simulate an operation performed on the subject user, the simulated operation being controlled by controlling the extension of the line.
- 25 18. A method according to claim 17 in which the simulated operation includes removal of portions of the computer-generated image to a depth within the patient indicated by the extension of the line.

19. A method for use by a user who performs an operation in a defined three-dimensional region with guidance from an image guided system, for modifying the image displayed to the user by the image guided system, the system including:

5 a data processing apparatus for generating an image of the subject of the operation in co-registration with the subject,

a display for displaying the image to the user, a probe having a position which is visible to the user, and

a tracking unit for tracking the location of the probe by the system and transmitting that location to the data processing apparatus,

10 the data processing apparatus modifying the image to represent a change in the physical shape of the subject of the operation, the modification depending upon the tracked location of the probe.

20. A method according to claim 19 wherein the data processing generates images of the subject of the operation overlaid on the subject.

15 21. A method according to claim 19 or 20 in which the data processing apparatus modifies the image simulating a removal of a part of the subject of the operation, the part being determined by the location of the probe

22. A method according to any of claims 11 to 21 in which the display is mounted on the head of a user, the user being able to view the subject of the operation
20 through the display, so as to see the computer-generated image superimposed on a true image of the subject of the image, the tracking unit monitoring the position of the display and transmitting the monitored position of the display to the processing apparatus, which modifies the computer-generated image according to the position of the display to maintain the computer-generated image and the real image
25 stereoscopically in register.

23. A method according to any of claims 11 to 21 in which the display is mounted on a microscope, the user being able to view the microscope image through the display, so as to see the computer-generated image superimposed on the

microscope image, the tracking unit monitoring the position of the microscope and transmitting the monitored position of the microscope to the processing apparatus, which modifies the computer-generated image according to the position of the microscope to maintain the computer-generated image and the real image
5 stereoscopically in register.

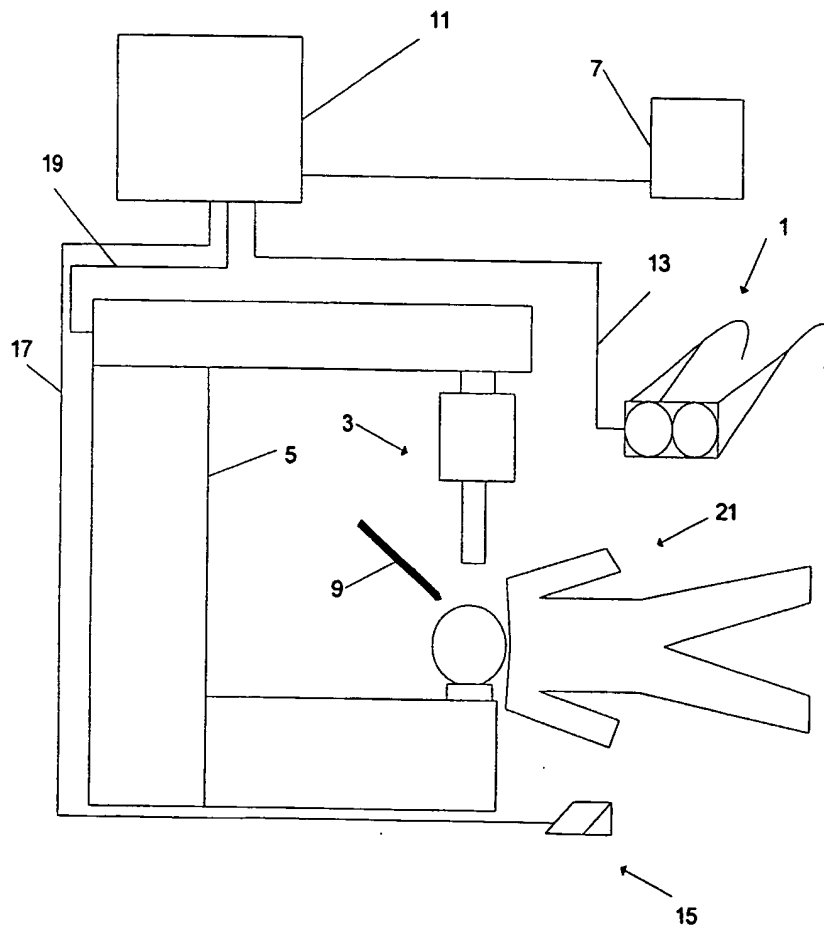


Fig. 1

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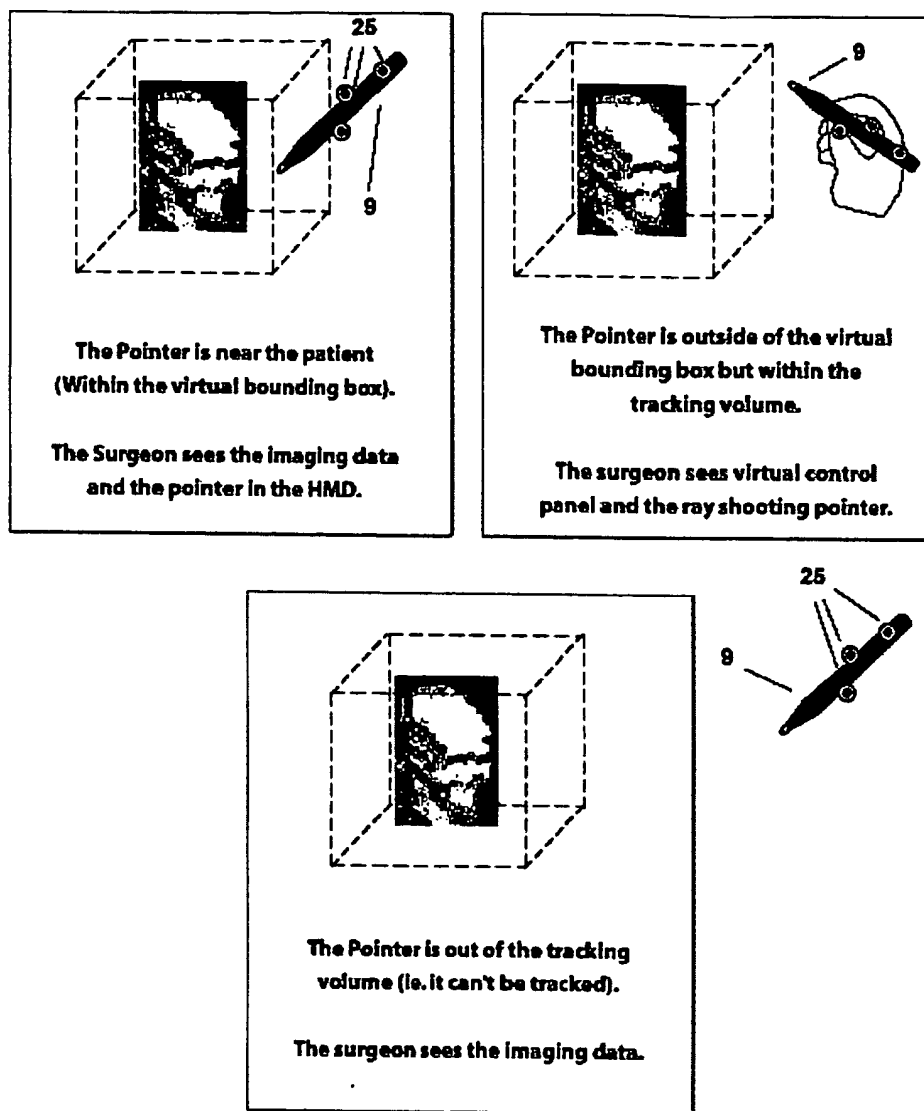
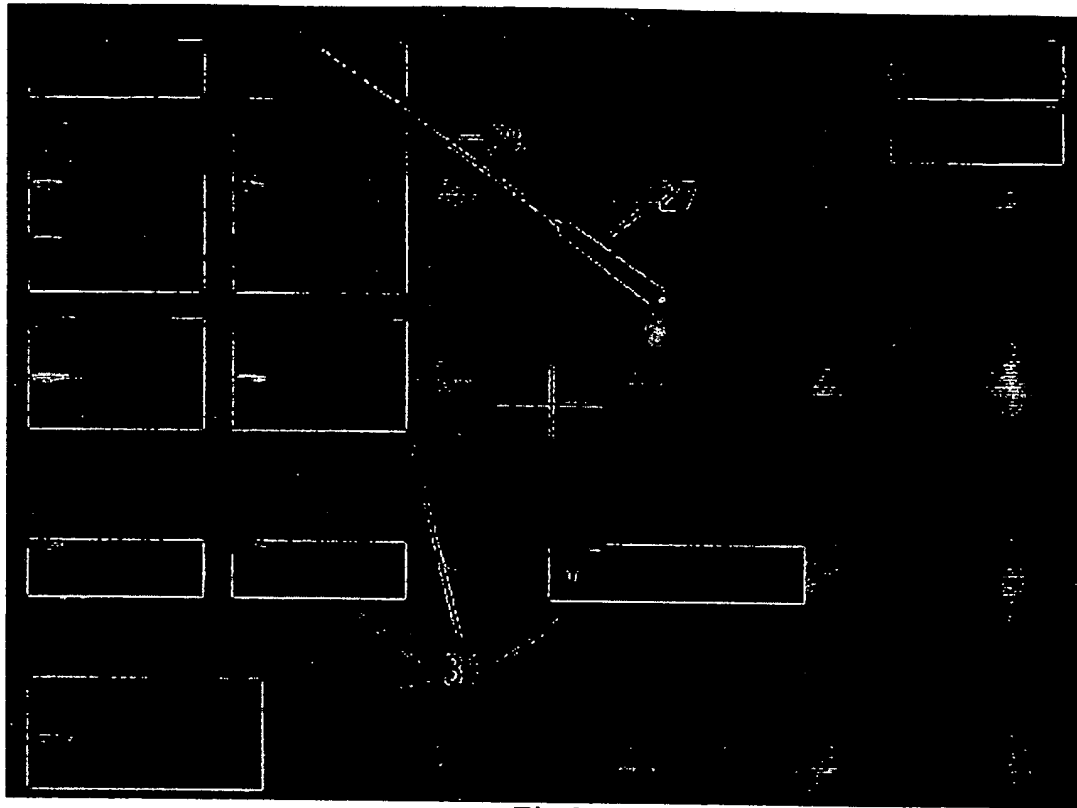


Fig. 2

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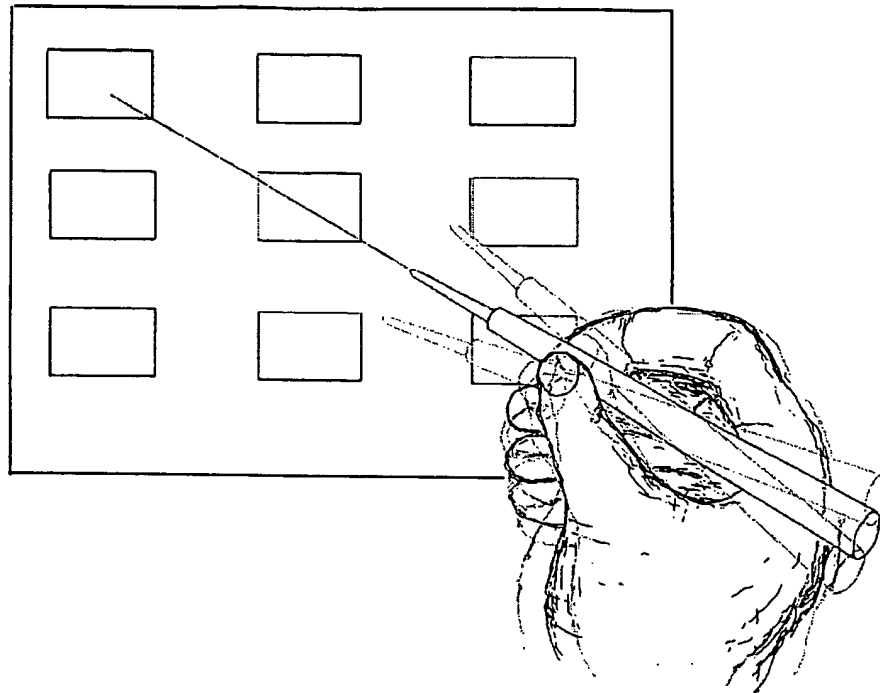


Fig. 4

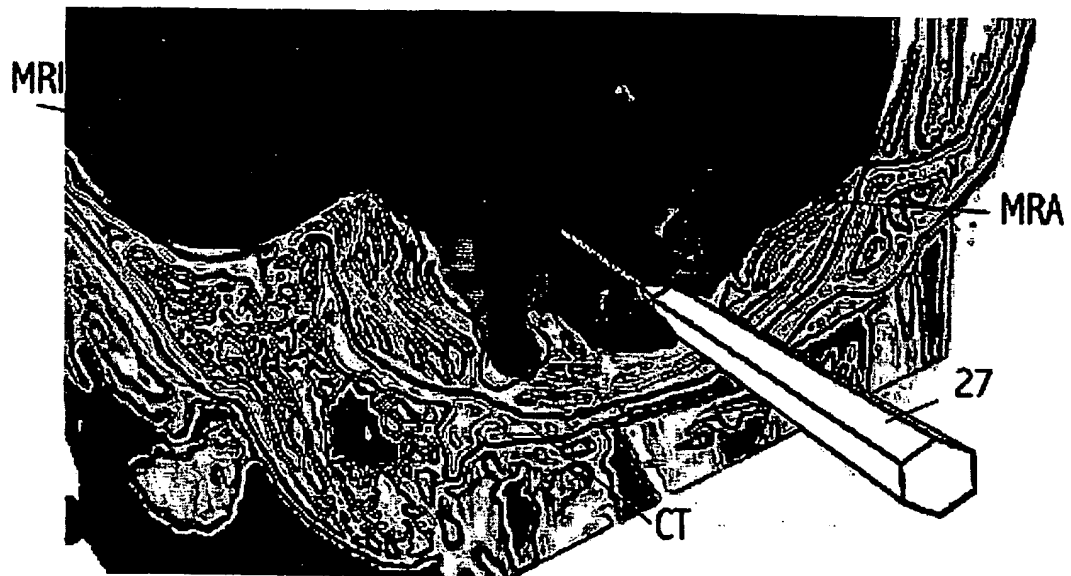


Fig. 5

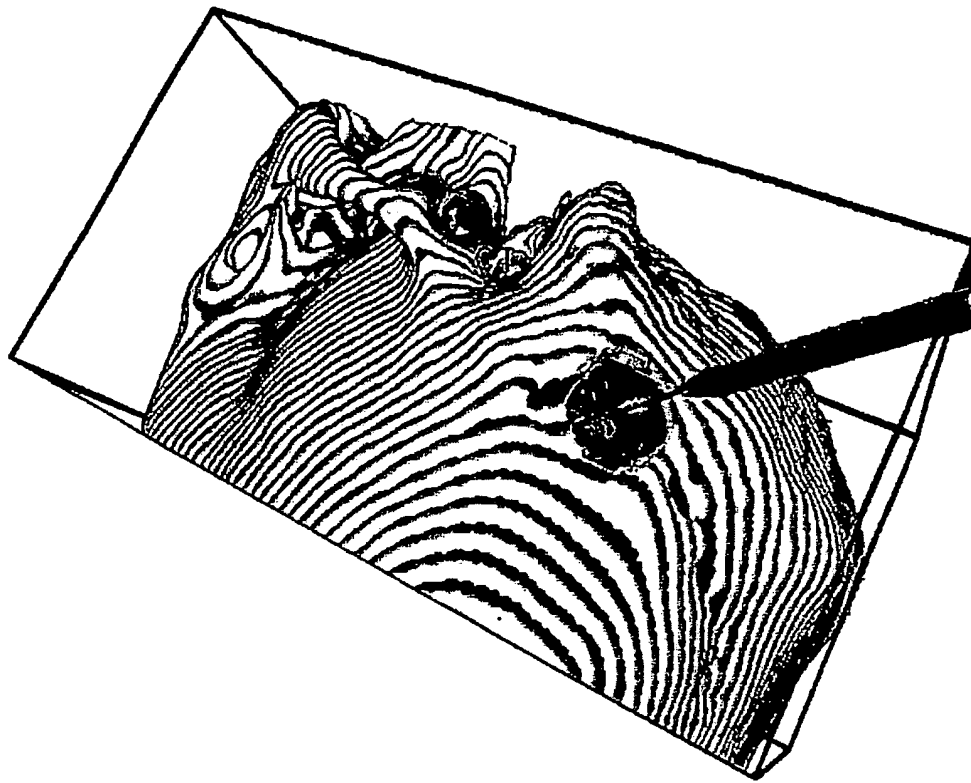


Fig. 6 a: Virtual image generated by the computer

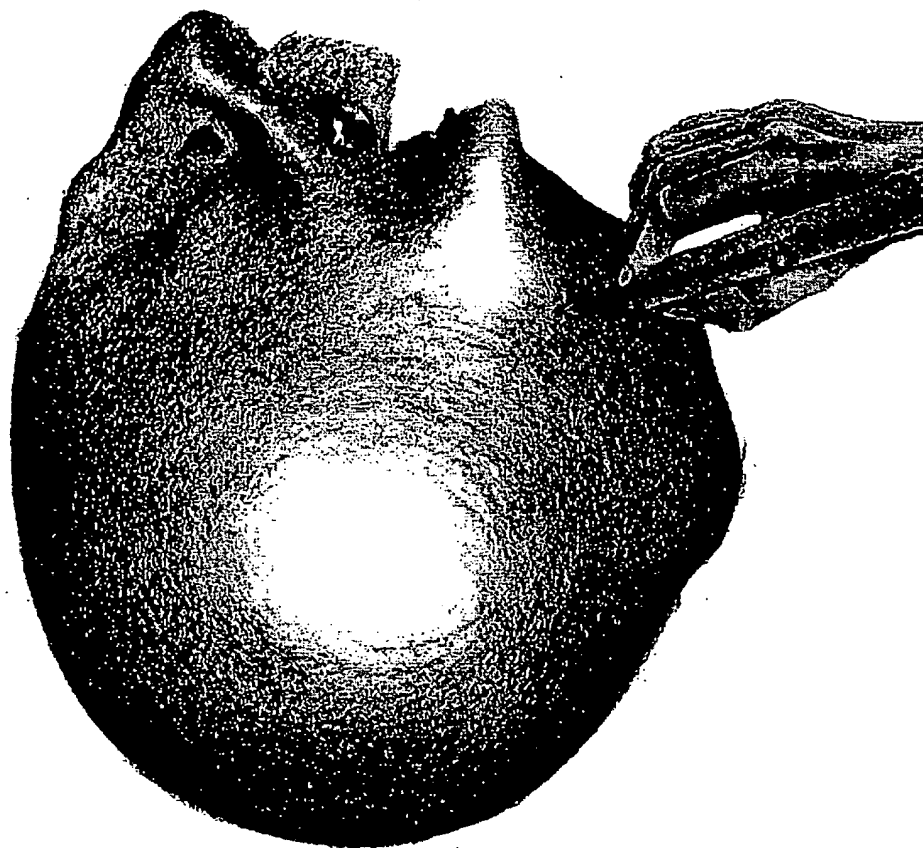


Fig. 6 b: Real image

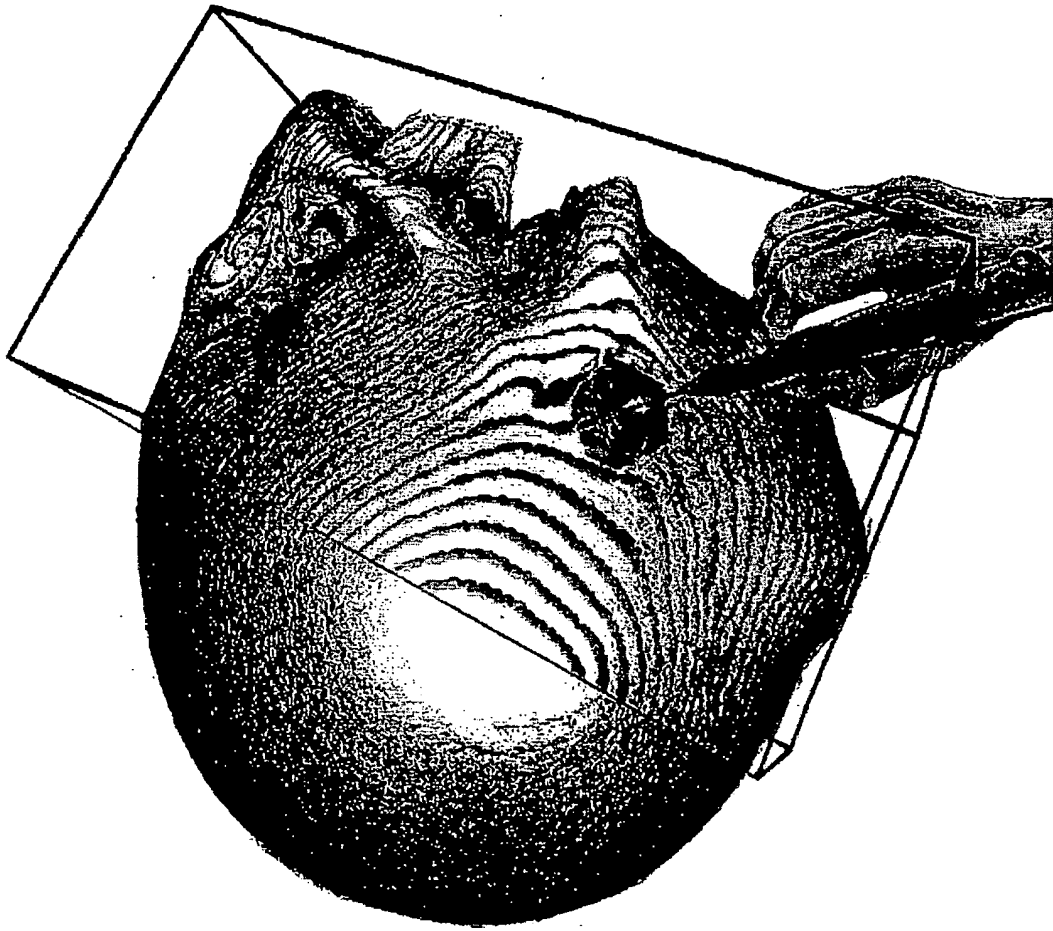


Fig. 6 c: Virtual and real images overlaid together

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG 01/00119

CLASSIFICATION OF SUBJECT MATTER

IPC⁷: A61B 19/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC⁷: A61B 17/00, 19/00; G06G 17/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, PAJ, EPODOC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99/60529 A1 (Nat.Univ.Singapore) 25 November 1999 (25.11.99) <i>the whole document; especially page 3, lines 13-24; page 4, line 28-page 5, line 5; page 5, lines 12-17, page 6, line 22 - page 8, line 15.</i>	1,6,11,14,19
A	US 5662111 A (Cosman E.) 2 September 1997 (02.09.97) <i>the whole document; especially claims 1-9.</i>	1,6,11,14,19
A	EP 0607000 A2 (Sun Microsystems) 20 July 1994 (20.07.94) <i>the whole document; especially abstract; page 2, line 44 - page 3, line 14; page 5, lines 17-52; fig. 5.</i>	1,6,11,14,19
A	US 5729475 A (Romanik C.) 17 March 1998 (17.03.98) <i>the whole document; especially abstract; column 13, lines 3-20; fig. 7.</i>	1,6,11,14,19

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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Date of the actual completion of the international search

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Austrian Patent Office
Kohlmarkt 8-10; A-1014 Vienna
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG 01/00119

Patent document cited in search report			Publication date	Patent family member(s)			Publication date
EP	A			none			
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